CARBON NANOTUBES AS A COLD ELECTRON BEAM SOURCE FOR PSEUDOSPARK PLASMA SWITCHES AND PULSED POWER APPLICATIONS

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Electron beam generated by a carbon nanotube coated cold cathode was used to control a pseudospark plasma switch for high-voltage and high-current pulsed power applications. A pseudospark switch operating at pressures of 10-30 mTorr has been designed and tested successfully.

Pseudospark plasma switches operate at low pressure-gap distance (p-d) products on the left hand side of a Paschen curve, like a thyratron tube, but have a much simpler construction (See Figure 1). Unlike streamer electrical breakdown in high pressure arcs that can cause often severe localized electrode erosion, pseudospark causes less electrode erosion while maintaining the capability of withholding high voltage and delivering high current. A pseudospark switch consists of two conductive metal electrodes in the shape of cups with holes at the center and surrounded by a good electrical insulator. The empty areas within the device contain gas at low pressures, typically between 25 and 100 mTorr. The typical dimensions of the holes and the spacing between the electrodes are between 2-5 mm. As the pressure drops and the p-d product decreases further towards the left-hand side of a Paschen curve, the mean free path for electron collisions with gas particles increases, the probability for electron impact ionization of gas particles in the 2-5 mm gap between two electrodes decreases, and a spark does not form in the gap between the two electrodes. Instead, a discharge may occur between the inside surfaces of the two hollow cup-shaped electrodes and flows through the holes at the center of the electrodes.

In order to convert the pseudospark gap into a good electrical switch to withhold high voltage and deliver high current an effective method for precise control of the switch is needed. These methods aim at releasing as large as possible a number of electrons inside the hollow cathode or near the volume between the cathode and the anode so that these electrons can multiply rapidly by electron impact ionization of gas particles under the acceleration by a very strong electric field. Electron multiplication causes plasma to be initiated, allowing the transition of the gas from its insulating state to the conducting state so that electrical current can flow with little resistance.

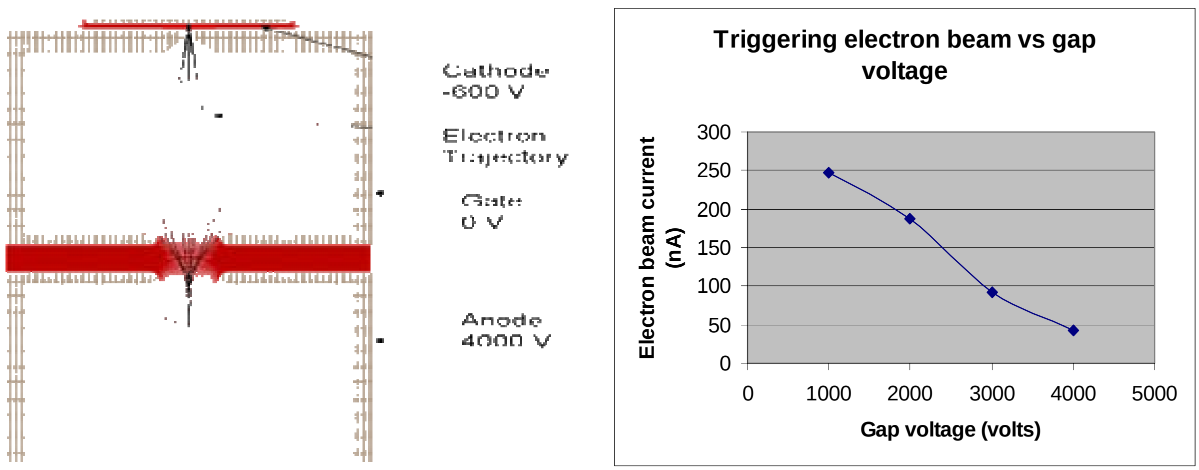
To optimize the operation of a compact high-voltage and high-current switch for repetitive pulsed power generation, a high-performance switch must have (i) low statistical delay jitter so that multiple switches can operate in parallel with precise timing, (ii) low delay time for fast turn-on of the switch, (iii) high repetitive rate, and (iv) a long life for the switch.

A Pseudospark switch with a carbon nanotube coated cold cathode as an electron beam source for controlling the switch is shown in Figure 1 (a). It consists of two conductive metal cups, which serve as two electrodes of the switch, with 3 mm diameter holes drilled at the center of the cups. The dimensions of the cups are 15 mm high and 18 mm in diameter. The copper cups are surrounded by a quartz tube with bottoms of the cups facing each other and having a gap between these two electrodes about 2 mm wide. A voltage is applied between the lower cup (the anode) and the top cup (the grounded cathode). The cathode is closed up with an aluminum plate with a 1 mm diameter hole to allow the injection of electrons into the hollow cathode. The cold cathode is a piece of silicon coated with thermal CVD multi-wall carbon nanotubes which are separated from the grounded aluminum plate by glass spacers of 350μm thick. The hole in the aluminum plate can be either aligned with the holes in the metal cups along the axis of the device or off-set by a distance.

Gas was fed into the Pseudospark to establish the desired gas pressure while the carbon nanotube coated cold cathode was maintained at a lower pressure by means of differential pumping through the 1 mm diameter hole on the aluminum plate that separates the carbon-nanotube cold cathode and the hollow cathode. The setup is pumped down to a base pressure of about 1×10^{-6} Torr before gas is fed into the Pseudospark gap. The gas flow rate is varied and the gas pressure inside the Pseudospark gap changes as a result between 10 and 40 mTorr.

Shown in Figure 1 (b) are the minimum electron beam current that is required to turn on a test pseudospark filled with argon gas as a function of the voltage applied between the hollow cathode and the anode. The required electron beam current injected from a carbon nanotube cold cathode for triggering the switch is only hundreds of nano-Amperes for an applied voltage well below the typical self-breakdown voltage of a Pseudospark. This electron current decreases with increasing applied voltage. Unlike thermionic electron sources, carbon nanotube cold cathodes do not need additional heating for electron emission and allow simplified design of the switch as well as little delay time. Moreover, the electron beam source is capable of providing a large supply of initiatory electrons, which help to reduce the statistical delay time (jitter) of the switch. This is highly desirable for fast and precise control of plasma switches.

In summary, application of carbon nanotube coated cold cathodes for high-voltage, high-current, plasma switches for pulsed power applications is reported. The demonstrated cold cathode triggered Pseudospark switch is free from severe thermal management difficulties unlike switches relying on thermionic electron emission for triggering, requires only a low voltage and a low electron current emitted from carbon nanotubes for turning on a high-voltage switch, and is very compact while potentially capable of controlling a very high-voltage when gases such as hydrogen instead of argon used for this test device are used to fill the switch, e.g. 100 kV, and high-current, e.g. 100 kA, pulsed power system using a stacked and parallel connected multiple Pseudospark switch package.



(a) (b)

Figure 1. (a) Schematic representation of a pseudospark switch and the computer simulated electron trajectories and electrical potential contours. (b) Electron beam current supplied by the carbon nanotube coated cold cathode that was required to turn on the pseudospark switch filled with argon gas at 30 mTorr at an applied voltage between 1kV and 4 kV.